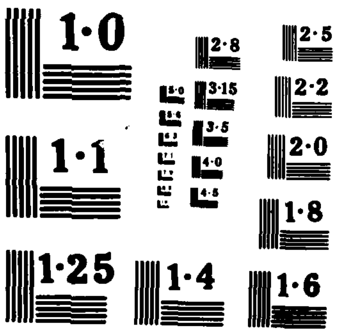
AD-A152 320 IMS (INTERNATIONAL MAGNETOSPHERIC STUDY) CONTRIBUTIONS TO THE UNDERSTANDI..(U) AEROSPACE CORP EL SEGUNDO CA SPACE SCIENCES LAB J F FENNELL 01 MAR 85 1/1

UNCLASSIFIED TR-0084A(5940-05)-2 SD-TR-85-06 F/G 4/1 NL

END

FILMED

DTIC


1·0
2·8
2·5
3·15
2·2
3·5
1·1
2·0
4·0
4·5
1·8
1·25
1·4
1·6

REPORT SD-TR-85-06

IMS Contributions to the Understanding of Auroral Precipitation, Transport, and Particle Sources

J. F. FENNELL
Space Sciences Laboratory
Laboratory Operations
The Aerospace Corporation
El Segundo, CA 90245

1 March 1985

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED

Prepared for

SPACE DIVISION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, CA 90009-2960

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-83-C-0084 with the Space Division, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009-2960. It was reviewed and approved for The Aerospace Corporation by H. R. Rugge, Director, Space Sciences Laboratory. First Lieutenant Douglas R. Case, SD/YCC, was the Project Officer for the Mission Oriented Investigation and Experimentation Program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Douglas R. Case
Douglas R. Case, 1st Lt, USAF
Project Officer

Joseph Hess
Joseph Hess, GM-15, Director, West Coast
Office, AF Space Technology Center

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER SD-TR-85-06	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IMS CONTRIBUTIONS TO THE UNDERSTANDING OF AURORAL PRECIPITATION, TRANSPORT, AND PARTICLE SOURCES		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER TR-0084A(5940-05)-2
7. AUTHOR(s) J. F. Fennell		8. CONTRACT OR GRANT NUMBER(s) F04701-83-C-0084
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Aerospace Corporation El Segundo, CA 90245		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Space Division Los Angeles Air Force Station Los Angeles, CA 90009-2960		12. REPORT DATE 1 March 1985
		13. NUMBER OF PAGES 34
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

auroral particles, polar regions, auroral plasmas, IMS,

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The progress in our understanding of plasma processes throughout the magnetosphere has increased dramatically during the International Magnetospheric Study (IMS) period. In this report the auroral ionosphere as a source of particles for the magnetosphere and the auroral particle acceleration and precipitation are emphasized. Some of the processes involved in the transport of particles from the ionosphere out into the magnetosphere are treated as well as the precipitation of magnetospheric particles into

cont

DD FORM 1473 (FACSIMILE)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19. KEY WORDS (Continued)

20. ABSTRACT (Continued)

the auroral and subauroral ionosphere. Some of the effects auroral ionospheric ions have on the magnetospheric plasma composition are described. A brief overview of pre-IMS results is also given to set the stage for a description of IMS contributions in these areas.

cont keywords include: [illegible]

CONTENTS

PREFACE 5

I. INTRODUCTION 7

II. PRE-IMS STATUS OF AURORAL PHYSICS 9

- A. Nightside Auroral Structure 9
- B. Dayside Auroral Structure 10
- C. Morningside Aurora 11
- D. Polar Cap 12

III. IMS CONTRIBUTIONS 13

- A. Nightside Auroral Region 13
- B. Dayside Auroral Regions 19
- C. Morningside Aurora 22
- D. Polar Cap 24

IV. FUTURE EFFORTS 27

REFERENCES 29

FIGURES

1. Auroral Crossing of the S3-3 Satellite on 6 Sept. 76 Showing Measurements from the UC Berkeley, Lockheed and Aerospace Instruments.. 15

2. Typical Auroral Particle Distributions Observed at ~1 R_e Altitude... 16

3. A Sketch of V-Shaped and S-Shaped Shocks............................ 17

4. Ionospheric Ion Outflow and Convection.............................. 21

5. Comparison of Evening and Morning Sector Auroral Electron Spectra.. 23

PREFACE

The author would like to thank all his colleagues who provided reprints of their work as source material for this report. This work was performed in part under USAF Contract F04701-83-C-0084.

I. INTRODUCTION

The International Magnetospheric Study program, or IMS, is a coordinated effort to understand magnetospheric processes. The IMS had two phases, the active phase during which data were gathered (from 1976 to 1979) and the data analysis and modeling phase which is winding down at this time. The major sources of data for the IMS program analysis phase have been identified in two recent publications, (Refs. 88, 137). These publications describe the data coverage and types of measurements made by satellite and ground-based systems plus some results from a few IMS workshops.

The symposium on the Achievements of the IMS took place at Graz, Austria (25-27 June 1984). The session on particle sources, transport, storage and precipitation included results related to auroral processes. In this rapporteur report the pre-IMS status of work in the area of auroral-processes is reviewed and the contributions the IMS program has made are described. The emphasis in this report will be on particles on auroral field lines. This includes the ionosphere as a source of particles, acceleration of auroral electrons and ions plus transport of the plasma. The focus will exclude the distant (> 10 Re altitude) tail observations which are covered elsewhere in these proceedings.

II. PRE-IMS STATUS OF AURORAL PHYSICS

This summary of the pre-IMS status does not reach back to the origins in auroral physics, that is a task for the historians. Instead, a brief description is presented of the understanding of auroral particle processes that obtained near the beginning of the IMS data collection period. This description is based on reviews of the subject from the 1974-1976 time frame. Emphasis is on the higher latitude polar regions; the auroral zone, polar cap and plasma sheet. By 1976 these regions had been observed by both low and high altitude spacecraft and rockets. Observations were also made from the ground using optical systems, magnetometers, radars etc. These had culminated in a fairly detailed picture of the general auroral morphology.

A. NIGHTSIDE AURORAL STRUCTURE

By 1976, the inverted V structure in the nightside auroral region had been observed and analyzed (Refs. 47, 108, 164). This latitudinal dependence of the precipitating electron energy was interpreted as a signature of electron acceleration via magnetic field-aligned electric fields (see Ref. 45). Such potential drops were also called upon to explain the field alignment of the precipitating electrons observed over discrete auroral arcs. The latitudinal structure of the acceleration was assumed to reflect the structure of the electric fields. Up to 1976 there were no decisive measurements which showed that parallel electric fields ($E_\parallel$) existed, that they were at low altitudes (1-2 Re altitude) or what the altitudinal scale length of such potential drops might be. There was, however, indirect evidence (Ref. 38).

There were objections to the concept of field-aligned potential drops, one being the existence of a large low energy component in the precipitating electrons. Evans (Ref. 37) showed that the intensities of precipitating and backscattered low energy electrons should be of similar magnitude. This idea was also supported by observations from spinning satellites (Refs. 7, 67, 107, 164) and rockets (Refs. 8, 9, 13). The precipitating electrons above discrete aurora were observed to be magnetic field-aligned (Refs. 13, 93 and ref. therein). In fact, measurements of the particle angular distributions showed

many features, most of which could be explained if one assumed a field-aligned electric field existed somewhere above the observation point (Refs. 4, 7, 13, 107, 108, 164). At times the precipitating electrons were observed to be strongly field-aligned over a wide range of energies. These observations often occurred at ionospheric levels and were associated with edges or boundaries of auroral displays (Refs. 125, 133, 161). Plasma instabilities at high ionospheric altitudes were suggested as mechanisms for forming such beams (Refs. 12, 81, 123, 126, 152-154).

By 1976 a few mechanisms had been proposed for generating field-aligned potential drops. A plasma instability which would lead to the formation of an anomalously increased resistivity and therefore a large voltage drop was one such mechanism. This required that while the bulk of the electron population is thermally heated the most energetic ones would pass through the instability region without collisions to be accelerated by the voltage drop. Alternatively, the plasma instability could lead to the formation of a confined electrostatic shock or "double layer." Electrons would be freely accelerated in the potential drop that forms across this region (Ref. 14). It was also proposed that parallel electric fields could result from the balance electric forces acting as charged particles in a converging magnetic mirror geometry, such as exists in the earth's magnetic field (Refs. 5, 87, 89-91). While there was some evidence to support each of these mechanisms there was not sufficient data to allow the models to be tested.

During the pre-IMS period observations of the energetic ion composition (< 20 keV/q) showed that the ionosphere was a significant source of ions (Ref. 146). The ionospheric ion content of the outer magnetosphere varied with magnetic activity. While there was much speculation as to how the ionospheric ions were energized and transported it was not until the IMS period that the answers came, as is discussed below.

B. DAYSIDE AURORAL STRUCTURE

Prior to 1976 the polar cusp particle precipitation had been observed and had been studied in some detail. The cusp signature was the simultaneous observation of magnetosheath-like ion and electron precipitation at latitudes

just above the energetic electron trapping boundary in the local noon sector of the auroral zone (Refs. 35, 45, 46, 63, 64, 163). The magnetosheath particles had access to low altitude and the access was highly variable (Refs. 100, 157). The HEOS2 measurements pointed to the existence of an entry layer, inside the dayside magnetopause, which connected to the plasma mantle (Ref. 135) and mid-altitude cusp (Refs. 55, 124). Examination of the plasma parameters near the mantle showed that they were consistent with an open magnetosphere (Ref. 34) as was the dispersion in the energy of precipitating ions in the low altitude cusp (Refs. 64, 132). This energy dispersion of ions in latitude under the control of the electric field ($\bar{E} \times \bar{B}$ drift) was observed at low and high altitudes (Refs. 132, 135, 149). This same mechanism was used to explain the ion temperature changes in the plasma mantle (Ref. 135). While this presented a nice simple picture of the origin of low altitude cusp particles, it wasn't always correct. Antisunward convection was observed near the cusp and there was significant variability in and reversals of the flow being observed there (Refs. 53, 60). These signatures required an interpretation in which the strict antisunward convection occurs only near local noon in the cusp and that away from noon the ExB flow is more consistent with being nearly parallel to the polar cap boundary (Ref. 60).

C. MORNINGSIDE AURORA

The morningside aurora had been somewhat neglected. Prior to 1976 it was depicted as a region of patchy precipitation like the eveningside diffuse aurora (Ref. 2). These precipitations would take on a structured appearance during the recovery phase of substorms, followed by the mantle aurora which spread through the local morning sector (Ref. 66). Satellite and ground-based auroral photographs showed that discrete auroras are generally absent in the morning sector (Refs. 1, 2). The dawnside auroral electron precipitation had the same form as the spectra of the dawnside plasmasheet electrons (Ref. 36). Often the patches of precipitation were associated with pulsations (Refs. 77, 136). The electron spectra of the pulsating aurora were observed to have a high energy tail and were not mono-energetic beams. From these features it was generally concluded that the central plasma sheet was the source of the morningside auroral electrons (Refs. 1, 2).

. POLAR CAP

The region above auroral zone latitudes had been studied to some extent. he polar rain (Ref. 109) and polar arc precipitations had been observed. The olar rain appeared to be controlled by the IMF (Ref 166). Examination of olar flare particle access to the tail lobes and high latitude polar regions rovided some information about magnetospheric topography (Ref. 160). The eneral antisolar convection had been observed and indications of sporadic olar-directed flow were noted (Ref. 60).

are usually soft and smooth varying with relatively low intensities (Refs. 104, 109, 166). The IMF controls the access of these electrons to the tail lobes and polar caps. The observed north-south pole precipitating flux asymmetries and tail lobe fluxes have been shown to be related to interplanetary solar electron anisotropies assuming direct access to the tail lobes and polar caps via an open magnetosphere model (Refs. 39, 52, 109, 166). This topic is currently being reexamined.

regions (Ref. 160). Unfortunately, nature does not cooperate by always providing flare electrons when one is trying to perform auroral observations.

There are particle features which are generally thought to occur in the open field line or polar cap region. A general class of observed features are the polar cap arcs and inverted V structures. These generally occur poleward of the convection reversal which is thought to define the boundary of open and closed field lines most of the time and to demark the northernmost edges of the auroral zones. These polar cap arcs have been described in detail using optical observations (Refs. 1-3, 48, 54, 62, 72, 73, 102, 120). There are relatively few polar cap arc optical observations for which the precipitating electron spectra are available and even fewer where combined particle, E field and current measurements are available (Ref. 17). In most cases either the optical or the particle data were available but not both. During the IMS period and earlier, only ISIS, DMSP and Kyokko could take such data (see for example, Refs. 6, 54, 56, 65, 78, 106, 109, 113). The resultant published correlations are few. Without the images it is difficult to decide whether the intense precipitations are truly in the polar cap. Even with them it is not obvious whether the arc precipitations are on open field lines or not. At present there is considerable controversy as to the source of the precipitating electrons. Are they plasma sheet, magnetosheath or tail lobe particles? There is no generally accepted answer at this time.

Much of the discussion of dayside polar convection patterns referenced in Sec. III.B above addresses this same question. The thing that has been missing is a self-consistent framework in which one can predict what the source of plasma is and how the arcs should appear. Recent papers by Chiu, et al., (23) and Reiff (129) provide probable frameworks. These models are based on an open model of the magnetosphere and discuss various ways magnetic merging occurs. The sources and configurations of the polar cap arcs are predicted by such models. It now remains for the observations to be compared to these models.

Finally, there is both pre- and post-IMS evidence that solar-wind/magnetosheath electrons obtain direct access to the polar cap. These fluxes

is driven by inward-convected anisotropic ions in the equatorial plane. On the eveningside these energetic ions (few keV) are predominately field-aligned, which dampens the mirror instability. On the morningside they are predominantly perpendicular to B. Thus the modulation of the pitch angle diffusion is most likely to occur in the morning sector.

The work on morningside aurora is not complete. As yet there is not a global model of the morningside aurora. Also, there is a question as to whether the discrete arcs associated with inverted V structures at high latitudes on the morningside (Refs. 67, 92) are precipitation of plasma on open or closed field lines. That is, are the inverted V structures observed there generated by accelerated magnetosheath particles and not precipitation from the morning side plasma sheet? There is some evidence pointing to this (Ref. 61).

D. POLAR CAP

The discussion of the polar cap is a tricky one. First, by the polar cap one usually means the extension of the magnetotail lobes to low altitudes. This corresponds to the region of open field lines. The exact point at which an observer defines the transition from open to closed (or vice versa) field lines to occur is generally biased by one's expectations of the physical processes which occur at that boundary combined with one's observational technique. So far, we have not been able to uniquely identify an open field line and this has led to much controversy in terms of interpretation of observations and in physical modeling.

Generally, in terms of particles, a field line is defined as open if a particle cannot perform bounce motion, i.e., it doesn't have a double loss cone. This has problems, for example, if the motion of particles is non-adiabatic, they will not always have an empty loss cone on a closed field line. If a potential drop forms on a field line, in a converging magnetic geometry, then a low energy particle component which cannot penetrate the potential structure will appear to be trapped, even if the field line is open. One technique, using particles which has been successful, has been to examine the access of energetic (> 40 keV) solar flare electrons to the polar

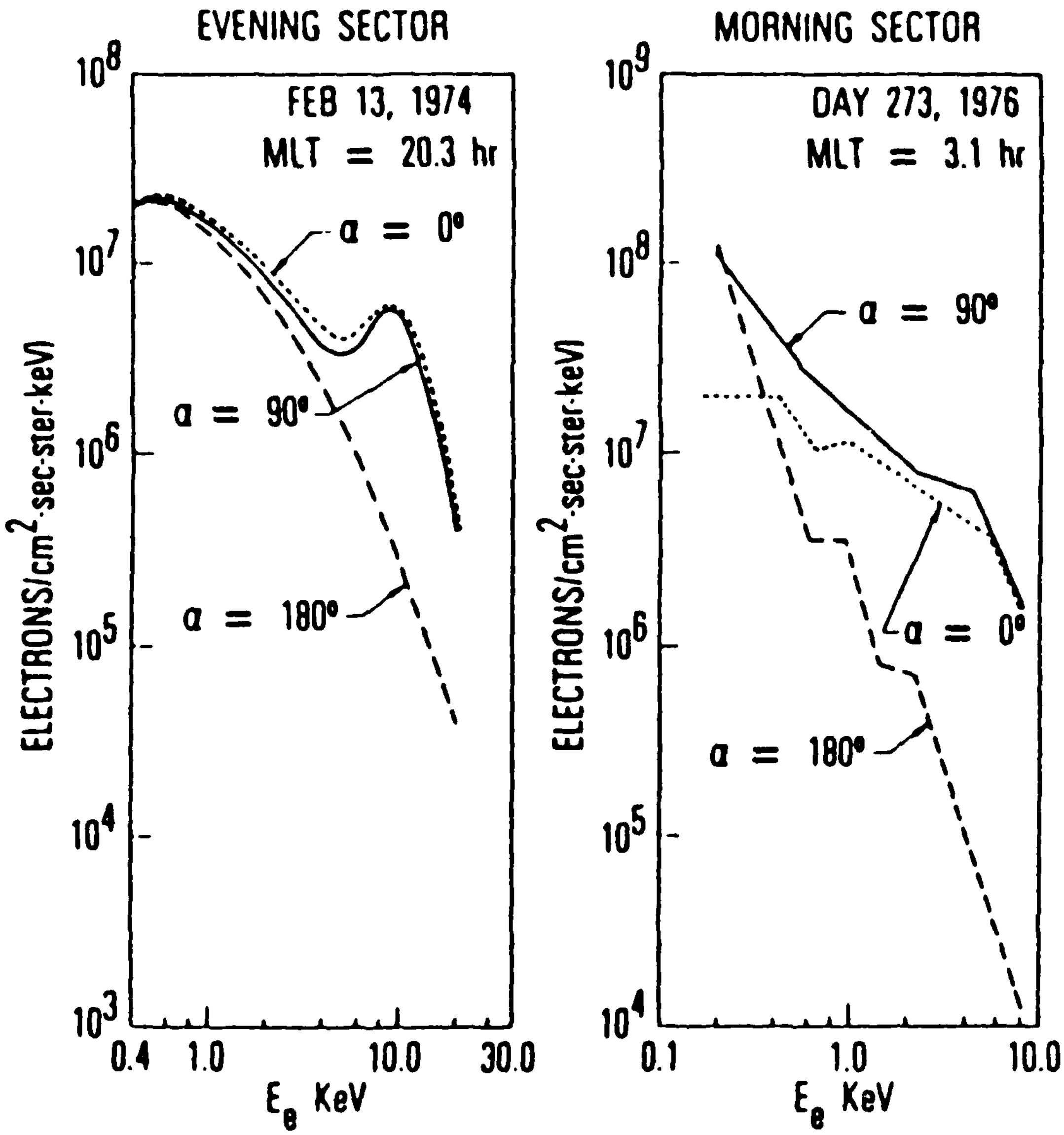


Figure 5. Comparison of evening (left panel) and morning (right panel) sector auroral electron spectra. The evening spectra show the usual electron beam formed by a field-aligned potential drop. The morning spectra is intense but monotonic, reminiscent of the morning plasmasheet.

Crooker (31) has generated a model of dayside merging which predicts the convection pattern in the dayside cusp. This description represents fairly well the observed features. More recently this kind of model has been expanded to include all local times and to make it more quantitative (Ref. 23).

C. MORNINGSIDE AURORA

Progress has also been made, both observationally and theoretically, in understanding the morningside aurora during the IMS. Observationally, the emphasis has been on finding the sources and mechanisms for the diffuse and pulsating electron precipitation (Refs. 3, 11, 24, 25, 30, 33, 105). On the morningside the separation of diffuse and discrete aurora has not been as clear cut as on the evening side where the diffuse aurora is located within the central plasma sheet and the discrete arcs are located in the boundary plasma sheet. The morningside discrete arc auroral fluxes generally do not show the monoenergetic peak associated with the eveningside arcs (Refs. 3, 24).

The morningside diffuse aurora is not as smooth and uniform as seen on the nightside. It develops patches which appear to drift with the background plasma and which often are pulsating (Refs. 24, 120). The precipitating electrons in these patches are still thought to be due to pitch angle scattering of the electrons and not due to field aligned potential drops (Refs. 105, 120). An example of a morningside precipitating electron spectrum is shown in Figure 5. There are few published electron spectra from the IMS period for the morningside auroral arcs for comparison with the surrounding diffuse-patchy structures. The majority of spectra were presented in the pre-IMS era (Refs. 47, 49).

Taking what is known about the morningside aurora and precipitation plus what has been recently learned about the equatorial plasma distribution on the morningside of the magnetosphere, Chiu, et al. (24) have constructed a theory of the morningside aurora. The theory is based on the spatial modulation of the warm plasma density caused by the mirror instability which in turn modulates the precipitation rates of the hot electrons. The mirror instability

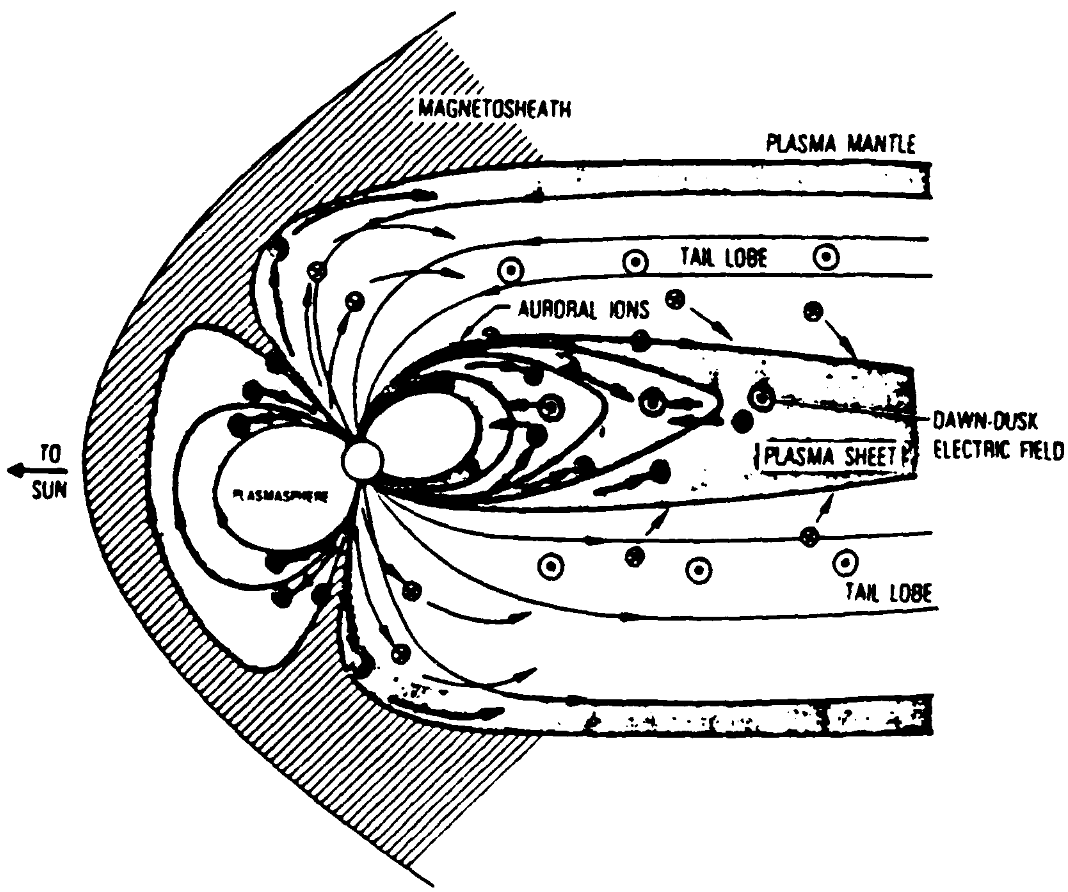


Figure 4. Ionospheric ion outflow and convection. Ion outflow is shown in and near the cusp, nightside auroral region and at subauroral latitudes of the plasmasheet. Convection transports these ions into the tail lobes and central plasmasheet.

are seen preferably at local noon in and near the cusp for moderate magnetic conditions (Refs. 51, 84). Klumpar (84, 85), using the ISIS data, found that the conic ions populate the cusp region field lines primarily in the summer hemisphere and that they are associated with intense beams of precipitating electrons. These cusp conics are often on nominally open field lines. This indicates that the ionosphere is providing ions to the magnetosheath in a layer next to the magnetopause (Refs. 127, 145) and to the polar cap regions via convection (Refs. 130-132, 135, 141). The composition and energy of the ionospheric ions in this layer will be determined by the acceleration mechanism and by convection as the ions move upward along the magnetic field lines. Generally the energies will be relatively low (< 1 keV or so). The convection electric field should also separate the ion species by acting as a crude velocity filter as has been observed elsewhere (Refs. 122, 135, 165) and as sketched in Figure 4. This has been observed recently by the DE-1 composition experiment (Refs. 21, 114).

The magnetosheath provides particles to the cusp as was discussed above. During IMS it was determined that some acceleration of the magnetosheath ions occurs at injection (Refs. 20, 158). So this source of cusp precipitation encompasses more than just particle scattering.

The plasma transport in the dayside auroral regions has been a topic of much interest. The visual evidence of auroral forms emanating from the polar cusp and discrete features extending into the polar caps (Refs. 2, 103, 104, 129, 131, 132) have resulted in a concerted effort to understand the plasma transport in this region (Refs. 23, 31, 57, 58). Observationally the auroral emissions are consistent with a throatlike convection of the plasma in the cusp and poleward (Refs. 57, 60, 61, 131). Similarly the direct measurements of plasma convection by AE-C show a throatlike convection pattern with the position of the throat and angle of flow into the polar cap being controlled by the interplanetary magnetic field (Refs. 57, 58, 62). More recently, it has been shown that a long term steady convection can effect the near cusp thermospheric flow when the interplanetary $B_y > 0$ (Ref. 101).

subauroral regions during substorms (see Sec. 2 and Refs. 75, 146). The post-IMS observations near the equator (Refs. 70, 71, 74, 76, 79, 80, 102, 122, 150, 168-171) showed that ionspheric ions are often present in the outer magnetosphere at the equator and are observed to be field-aligned (Refs. 18, 19, 42, 43, 70, 79, 80, 95, 96). These facts lead to the conclusion that the auroral ionosphere is a significant source of plasma to the outer magnetosphere. At times, especially during large storms, it is the dominant source and the relative strength may vary with the solar cycle (Refs. 29, 74, 168-170). ISEE-1 observations have shown that in the plasma sheet and tail lobes there is a population of low intensity streaming ions of recent ionospheric origin which form the dominant plasma constituent (Refs. 141, 143). All of the IMS results indicate that the auroral ionosphere supplies a significant fraction of the plasma sheet and outer magnetosphere plasma.

More recently, the near earth central plasma sheet has been restudied as part of the IMS (Refs. 10, 40) with emphasis on the plasma motions. One study (Ref. 40) has concluded that the inner edge plasma sheet electrons are seldom strongly pitch-angle-scattered and their motions through the magnetosphere are convection-dominated. Other studies organize the plasma motion by calling on a near-earth source or injection boundary with convection controlling the motions earthward of the boundary (Refs. 98, 99). In another area, examinations of the afternoon radar-aurora signatures shows these to be most likely associated with the inner edge of the diffuse precipitation of plasma sheet electrons and the weakening of the convection electric field (Ref. 121). Recently auroral images have shown that the equatorward edge of the evening diffuse aurora has undulations probably related to the plasma convection just outside the plasmasphere (Ref. 94). The processes which form these structures are not known yet.

B. DAYSIDE AURORAL REGIONS

The IMS dayside studies have not had the great impact on the auroral physics problem that the nightside studies have. Nevertheless, there has been advancement in our understanding. The auroral ion sources seen on the nightside are also present on the dayside. In fact, the upflowing conic ions

less than the potential drop across the shocks (Ref. 155). The shocks themselves typically span a latitudinal width of 0.01° to 0.1° and it has been proposed that discrete auroral arcs are produced by electron acceleration in the shocks (Refs. 83, 159). The sizes of the electrostatic shocks scale as the ion gyroradius and their electric field orientation is predominantly perpendicular to B (Refs. 116, 117, 159). These shocks are also imbedded in regions of coherent electrostatic ion cyclotron (EIC) waves.

It has been shown (Ref. 82) that the EIC waves are associated with the beams of upflowing ions. The temperature of these ion beams (see Figure 2) indicates that some heating of the ions has occurred. The energy of the beam is assumed to represent the field-aligned potential drop below the observation altitude (Refs. 42, 43, 50, 155). The observation of ion conics (Refs. 44, 51, 74, 84, 86, 139, 162) on ISIS, S3-3 and on rockets gave some ideas for the source of this ion heating. The conics were found to be accelerated preferentially perpendicular to the magnetic field and to originate predominantly at lower altitudes (< 4000 km) in the auroral zone (Ref 51), as low as a few hundred kilometers altitude (Ref. 162).

The composition of the upflowing ions showed that oxygen was a significant fraction of the total ion density in the inverted V regions (Refs. 139-142, 148). A study by Collin, et al., (Ref. 27) showed that the upflowing oxygen ions derived about half of their energy from a mass dependent process (heating?) whereas the hydrogen ions derived most of their energy from a quasistatic parallel potential drop. The oxygen ion energy always exceeded that of the hydrogen giving rise to the speculation that the oxygen ions may be the dominant ion in the conic energization process. The energy of the upflowing oxygen was found to track the energy of the precipitating electrons (Ref. 140 and references therein), as did the hydrogen. This is consistent with the concept that ions and electrons are simultaneously accelerated on the auroral field line, partially in a parallel potential drop and partially via waves.

The observation of these upflowing ionospheric ions fit well with the pre-IMS observation of ionospheric ions being present and precipitating in the

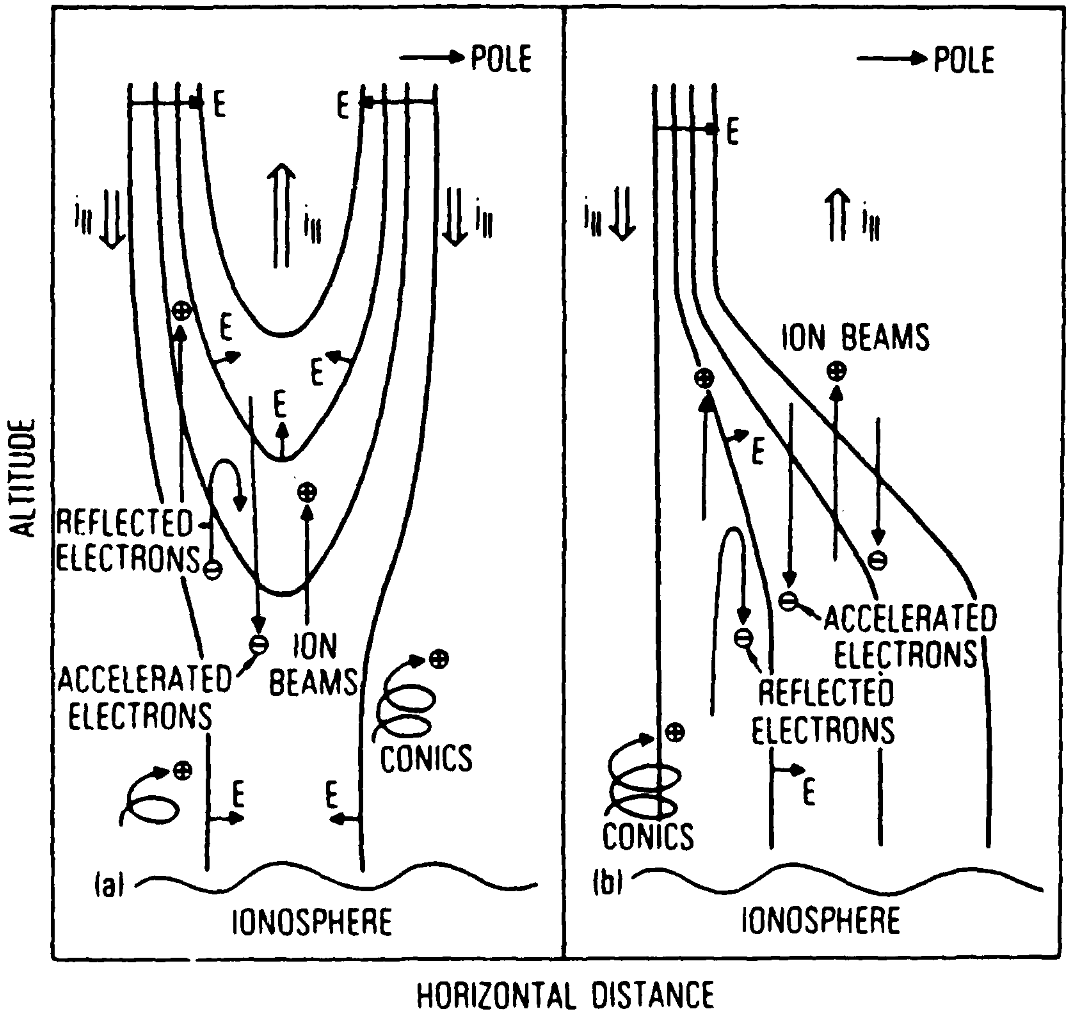


Figure 3. A sketch of V-shaped (left panel) and S-shaped (right panel) shocks. The kinds of particle distributions seen near and in the shocks are also shown (after Refs. 112 and 118).

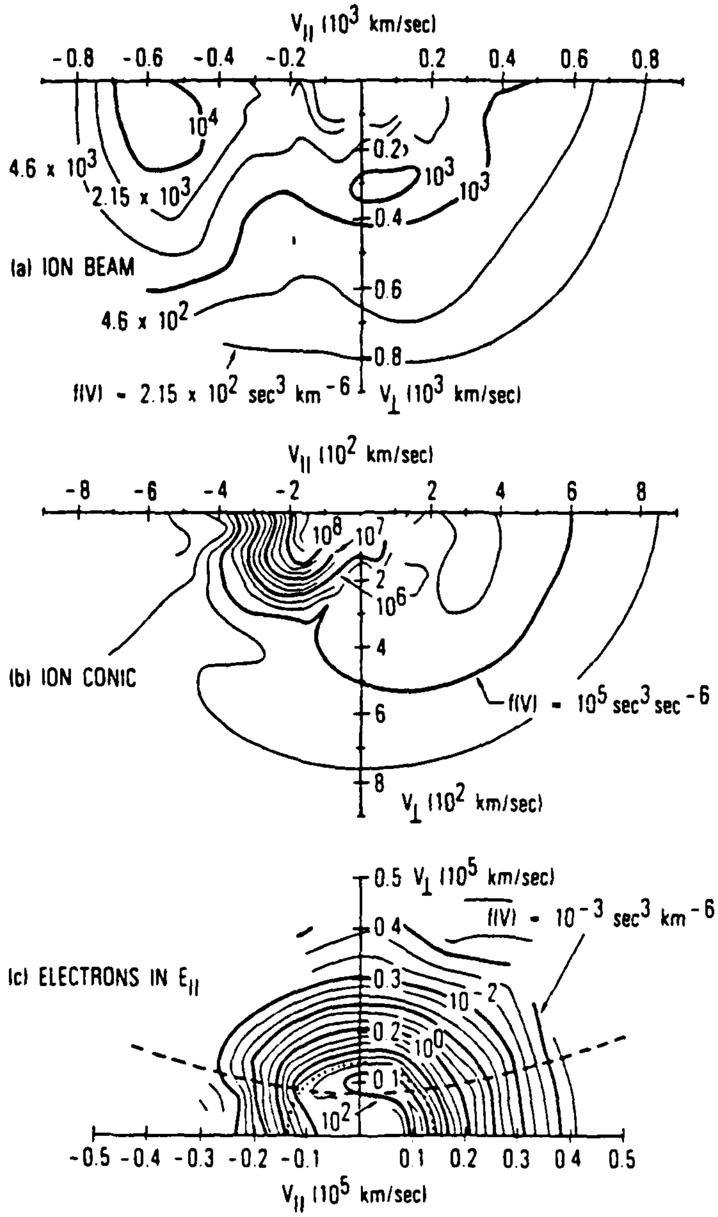


Figure 2. Typical auroral particle distributions observed at $\sim 1\ R_e$ altitude. (a) Upflowing ions in the dusk sector which show effects of a potential drop below the observation altitude. Note perpendicular spread of beam. (b) Upflowing ion conic distribution with peak of f(v) lying near a cone with opening angle of ~35° relative to $-V_{\parallel}$ axis. (c) Accelerated electrons with a peak in the downgoing direction. The distribution shows effects of a potential drop above and below the observation point (after Ref. 22).

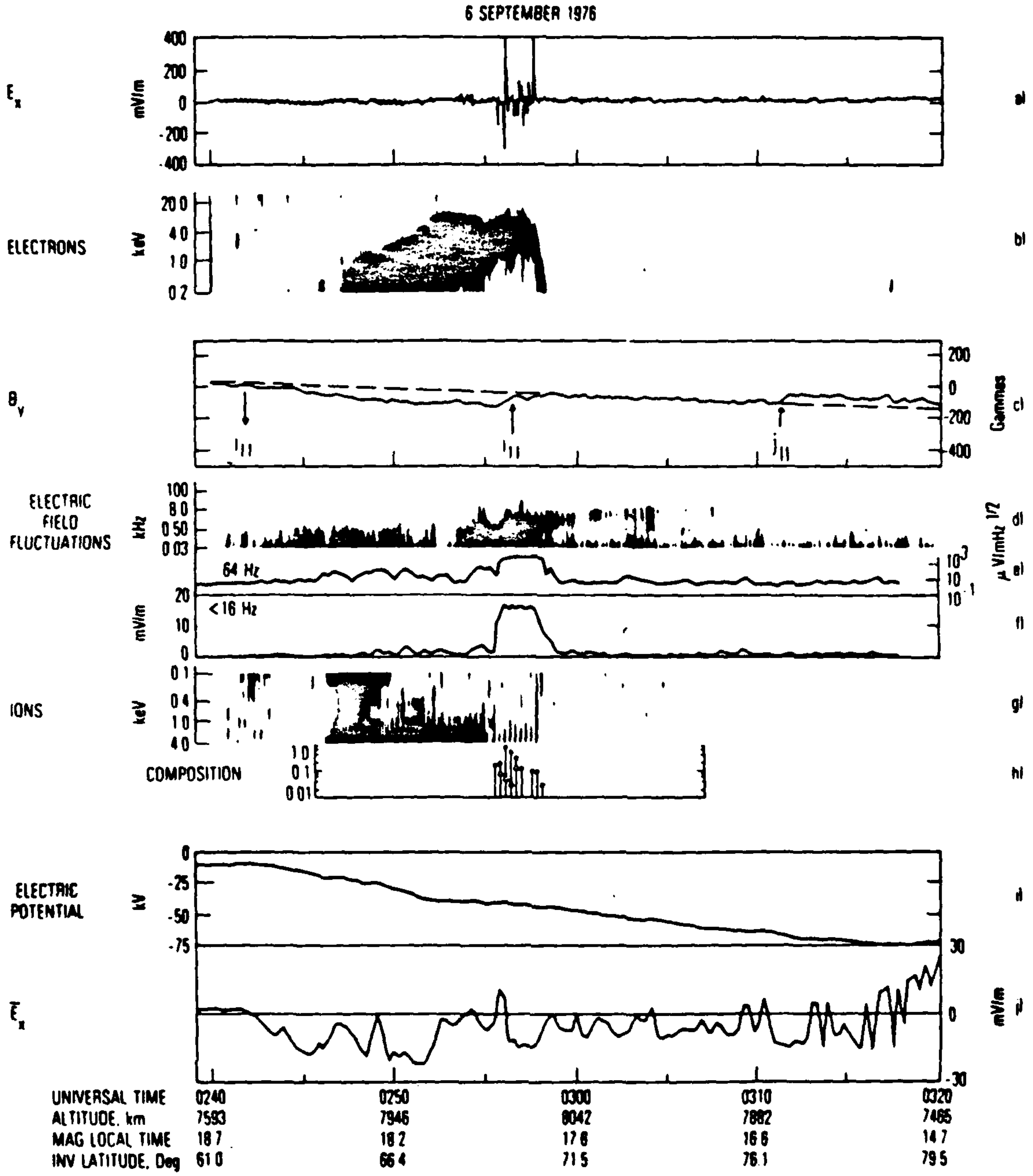


Figure 1. Auroral crossing of the S3-3 satellite on September 6, 1976 showing measurements from the UC Berkeley, Lockheed, and Aerospace instruments: (a) high resolution dc electric field in the north-south direction; (b) energy-time spectrogram of electrons with $0.17 < E < 33$ keV; (c) east-west currents inferred from averaged magnetic perturbations; (d) frequency-time spectrogram of ac electric fields with $0.032 < f < 100$ kHz; (e) frequency band near 64 Hz; (f) frequency band near 16 Hz; (g) energy-time spectrogram of ions with $0.09 < E < 3.9$ keV; (h) the fraction of helium oxygen and hydrogen in the upflowing ion beams; (i) integrated electric field potential; and (j) spin averaged north-south electric field (after Mizera et al., 1981).

ISEE1 and 2 provided detailed looks at the outer magnetosphere especially the magnetopause, nightside plasmasheet and tail lobes.

Figure 1 shows a summary of the kinds of data obtained from S3-3 (Ref. 110). Essentially, such data were used to ascertain that the field-aligned potential drops in inverted V structures extended a few thousand km above and below the observation altitude (Refs. 22, 43, 118, 140, 142). The physical mechanisms which formed the potential drop left the electron distribution functions with the appearance of a relatively scatter-free motion along the auroral field lines (Refs. 22, 32). This led to a series of models of the auroral potential structure which emphasized the kinetic theory approach based on the Maxwell-Vlasov equations (Refs. 22, 23, 26, 28, 30, 145). Figure 2 shows typical examples of such electron and ion distribution functions. Other authors have presented significantly different points of view concerning the generation of the potential drop, which were also mentioned in Section II (Refs. 41, 68, 69, 97, 118, 144 and references therein).

The electric field data from both S3-2 and S3-3 show the signature of electrostatic shocks (Refs. 15, 16, 116, 118, 155). These were first observed during the IMS. The small scale ones have been interpreted as double layers (Ref. 156). At ionospheric altitudes shocks were rare whereas at $\sim 1\ R_e$ altitude they were fairly common. The higher altitude shocks were seen with E field magnitudes as large as a few tenths of a volt per meter. Using ISEE-1 data, Mozer (Ref. 115) has shown that the auroral electrostatic shocks are most likely confined to altitudes less than a few R_e. Some times (< 50% of the time) these structures consist of paired oppositely-directed electric fields; at other times (> 50% of the line) these structures consist of electric fields of one sign and are usually called S-shaped shocks (Refs. 112, 115, 116, 155). Schematic electric equipotentials for each kind of shock are shown in Figure 3 along with the types of particle distributions observed. Normally these shocks are imbedded in a region of low frequency turbulence and are often associated with VLF saucer emissions (Refs. 116, 118). They are generally found within the inverted V structures and are associated with up-streaming beams of ions (Ref. 111) that have an energy comparable but somewhat

III. IMS CONTRIBUTIONS

During the period from the beginning of the IMS in 1976, through the observation phase in 1979, and to the present, an enormous amount of effort was put forth to understand the auroral system. As far as particle observations are concerned, not all the studies during 1976 to the present were strictly IMS-related. Many had begun prior to the IMS or utilized data sets generated prior to 1976. Nevertheless, they are included here because many pre-IMS data sets have been more thoroughly analyzed under the auspices of the IMS and they are important to our present understanding. The results from the AE (see Refs. 57-61, 92, 93, 130, 131), the ISIS (Refs. 63, 84-86, 164), and the DMSP (Refs. 2, 103-108, 113, 119, 120 and references therein) satellites have been invaluable in bringing us to our present understanding of the physical processes which occur on auroral and polar cap field lines. These pre-IMS data were combined with IMS data sets (Ref. 137) to yield a much more detailed understanding of the sources, transport, and precipitation of particles on auroral field lines. The sections that follow treat the auroral regions in the same manner as in Section II above, by separating different local time and latitude regions.

A. NIGHTSIDE AURORAL REGION

As was described above, the mechanisms for generating the nightside diffuse aurora were fairly well understood but several different theoretical descriptions of the discrete aurora and inverted V structures existed prior to the IMS. Significant new data sets were added very early in the IMS period with the orbiting of the AE-D, S3-2, S3-3, and GEOS satellites. These were joined by the many ground-based networks, new DMSP satellites, and the ISEE, Prognoz, SCATHA and MAGSAT satellites. In particular, the GEOS, ISEE and SCATHA satellites (Ref. 137) gave us a more detailed picture of the outer plasmasheet structure and S3-3 provided, for the first time, a direct look at the nightside auroral acceleration region. S3-2 and AE-D and AE-C provided a detailed look at the processes which occurred at ionospheric altitudes.

IV. FUTURE EFFORTS

The gaps in our understanding of the sources, transport and precipitation of particles on auroral field lines are many. Some we have started to look at. For example, we are already looking into the sources of the polar cap plasmas and arcs with the Dynamics Explorer satellite (Refs. 21, 48). More detailed studies of these regions are planned for in the ISTP program which we hope will see observation platforms being launched late this decade. More detailed studies of the auroral acceleration, convection, and precipitation processes in the auroral oval are needed. Again we have started some of this work with Dynamics Explorer (Refs. 147, 165, 167) which emphasizes the auroral regions. AMPTE was recently launched and will be joined in 1985 by the VIKING satellite. AMPTE will try to solve the global plasma source and transport problem in the equatorial magnetosphere while VIKING will emphasize the auroral regions in the 1 to 2 R_e altitude polar regions. These programs will help fill observational gaps which presently exist, especially when it comes to plasma sources and in analyzing plasma transport and wave-particle interactions. These satellites will have comprehensive plasma composition and AC-DC field measurements necessary to provide the details now missing.

The ground-based observatories are continuing to be upgraded. The observational coverage is nearly worldwide now and ranges from simple magnetometer stations to sophisticated radar systems for tracking conductivities and plasma motions in the ionosphere. Shortly we will have continuous maps of the auroral and polar cap ionospheric conditions to use in the sophisticated models which are being built. The rest of this decade should indeed continue the rapid advancement of understanding of the auroral processes which has occurred during the IMS period.

REFERENCES

1. Akasofu S -I 1974, Discrete, continuous and diffusive auroras, Planet Space Sci 22, 1723.

2. Akasofu S -I 1977, Physics of Magnetospheric Substorms, D Reidel, Dordrecht-Holland.

3. Akasofu S -I 1981, Auroral arcs and auroral potential structure, in Physics of Auroral Arc Formation, I, Akasofu & Kan eds, AGU, Washington DC.

4. Albert R D & Lindstrom P J 1970, Auroral-particle precipitation and trapping caused by electrostatic double layers in the ionosphere, Science 170, 1398.

5. Alfvén, H A & Fälthammer,C G 1963, Cosmical Electrodynamics 28, 2nd ed Oxford Press, London.

6. Anger C D 1979, Photometric imaging of the aurora from the ISIS-2 satellite, in Magnetospheric Study 1979 1, Japanese IMS Committee, Tokyo.

7. Arnoldy R L 1981, Review of auroral particle precipitation, in Physics of Auroral Arc Formation, Akasofu & Kan eds, Am Geophysical Union, Washington, D.C.

8. Arnoldy R L & Choy L W 1973, Auroral electrons of energy less than 1 keV observed at rocket altitudes, J Geophys Res 78, 2187.

9. Arnoldy R L et al 1974, Field-aligned auroral electron fluxes, J Geophys Res 79, 4208.

10. Bahnsen A et al 1984, Morphology of keV-Electrons in the Earth's Magnetosphere, in Achievements of the IMS, 25th COSPAR meeting.

11. Berkey F T 1980, Temporal fluctuations in the luminosity of diffuse auroras, J Geophys Res 85, 6075.

12. Bingham R et al 1984, A wave model for the aurora, Geophys Res Letters 11, 327.

13. Boyd J S 1975, Rocket-borne measurements of auroral electrons, Rev of Geophys and Sp Physics 13, 735.

14. Block L P 1975, Double layers, in Physics of the Hot Plasma in the Magnetosphere, B Hultquist & L Stenflo eds, 229, Plenum, New York.

15. Burke, W. J. et al 1984, High latitude electrodynmaic observations from S3-2, Space Sci Rev 37, 161.

16. Burke W J 1981, Electric fields, Birkeland currents and electron precipitation in the vicinity of discrete auroral arcs, in Physics of Auroral Arc Formation, S -I Akasofu & J R Kan eds, AGU Washington, 164.

17. Burke W J et al 1982, Electric and magnetic field characteristics of discrete arcs in the polar cap, J Geophys Res 87, 2431.

18. Candidi M et al 1984, Observations of multiple ion beams in the magnetotail: evidence for a double proton population, J Geophys Res 89, 2180.

19. Candidi M & Orsini S 1984, The ionospheric O^+ streams in the nightside magnetosphere between 22 R_e and 6 R_e, in Achievements of the IMS, 25th COSPAR meeting.

20. Carlson C W & Torbert R B 1980, Solar wind ion injections in the morning auroral oval, J Geophys Res 85, 2903.

21. Chappell C R 1984, The flow of ionospheric plasma into the earth's magnetosphere, Adv Space Res, to be published, COSPAR.

22. Chiu Y T et al 1983, Auroral plasmas in the evening sector: satellite observations and theoretical interpretations, Space Sci Rev 35, 211.

23. Chiu Y T et al 1984, Model of oval and polar cap arc configurations, J Geophys Res to be published.

24. Chiu Y T et al 1983, Mirror instability and the origin of morningside auroral structure, J Geophys Res 88, 4041.

25. Chiu Y T & Kishi A M 1984, Kinetic model of auroral plasma formation by magnetospheric convection and injection; 1, Electrons, submitted to J Geophys Res.

26. Chiu Y T & Schulz M 1978, Self-consistent particle and parallel electrostatic field distributions in the magnetospheric-ionospheric auroral region, J Geophys Res 83, 629.

27. Collin H L et al 1981, Some general characteristics of upflowing ion beams over the auroral zone and their relationship to auroral electrons, J Geophys Res 86, 6820.

28. Collin H L et al 1982, The occurrence and characteristics of electron beams over the polar regions, J Geophys Res 87, 7504.

29. Collin H L et al 1984, The magnitude and composition of the outflow of energetic ions from the ionosphere, J Geophys Res 89, 2185.

30. Cornwall J M & Chiu Y T 1982, Ion distribution effects of turbulence on a kinetic auroral arc model, J Geophys Res 87, 1517.

31. Crooker N U 1979, The configuration of dayside merging, in Dynamics of the Magnetosphere, S -I Akasofu ed, 101.

32. Croley D R Jr et al 1978, Signatures of a parallel electric field in ion and electrons in velocity space, J Geophys Res 83, 2701.

33. Davidson G T 1979, Self-modulated VLF wave-electron interaction in the magnetosphere: a cause of auroral pulsation, J Geophys Res 84, 6517.

34. Dungey J W 1961, Interplanetary magnetic field and the auroral zones, Phys Rev Letters 6, 47.

35. Dyson P L & Winningham J D 1974, Topside ionospheric spread F and particle precipitation in the dayside magnetospheric clefts, J Geophys Res 79, 5219.

36. Eather R H et al 1976, Plasma injection at synchronous orbit and spatial and temporal auroral morphology, J Geophys Res 81, 2805.

37. Evans D S 1974, Precipitating electron fluxes formed by a magnetic field aligned potential difference, J Geophys Res 79, 2853.

38. Evans D S 1975, Evidence for the low altitude acceleration of auroral particles, in Physics of the hot plasma in the magnetosphere, Hultquist & Stenflo eds, 319, Plenum Press, New York, N Y.

39. Fairfield D H & Scudder J D 1984, The polar rain: the solar wind strahl in the magnetosphere, J Geophys Res to be published.

40. Fairfield D H and Vinas A F 1984, The inner edge of the plasma sheet and the diffuse aurora, J Geophys Res 89, 841.

41. Fälthammer, C -G 1978, Generation mechanisms for magnetic field aligned electric fields in the magnetosphere, J Geomag and Geoelectr 30, 419.

42. Fennell J F et al 1981, Low-energy ion pitch angle distributions in the outer magnetosphere: Ion zipper distributions, J Geophys Res 86, 3375.

43. Fennell J F et al 1981, Auroral particle distribution functions and their relationship to inverted Vs and auroral arcs, in Physics of Auroral Arc Formation, Akasofu & Kan eds, 91, Am Geophysical Union, Washington, D C.

44. Fennell J F et al 1979, Observations of ion and electron distributions during the July 19 and July 30, 1977 storm period, in Proceedings of Magnetospheric Boundary Layers Conference, Alpbach.

45. Frank L A 1975, Magnetospheric and auroral plasmas; a short survey of progress, Rev of Geophys and Space Physics 13, 974.

46. Frank L A & Ackerson K L 1971, Observations of charged particle precipitation into the auroral zone, J Geophys Res 76, 3612.

47. Frank L A & Ackerson K L 1972, Local time survey of plasma at low altitudes over the auroral zones, J Geophys Res 77, 4116.

48. Frank L A et al 1982, Polar views of the Earth's aurora with Dynamics Explorer, Geophys Res Lett 9, 1001.

49. Frank L A et al 1976, Electron precipitation in the postmidnight sector of the auroral zones, J Geophys Res 81, 155.

50. Ghielmetti A G et al 1978, The latitudinal, diurnal, and altitudinal distribution of upward flowing energetic ions of ionospheric origin, Geophys Res Letters 5, 59.

51. Gorney D J et al 1980, The distribution of ion beams and conics below 8000 km, J Geophys Res 85, 83.

52. Gosling J T 1984, ISEE-3 plasma measurements in the lobes of the distant geomagnetic tail: inferences concerning reconnection at the dayside magnetopause, in Magnetic Reconnection in Space and Laboratory Plasmas, Hones ed., AGU Washington D C.

53. Gurnett D A & Frank L A 1973, Observed relationships between electric fields and auroral particle precipitation, J Geophys Res 78, 145.

54. Gussenhoven M S 1982, Extremely high latitude auroras, J Geophys Res 87, 2401.

55. Haerendel G & Paschmann G 1975, Entry of solar wind plasma into the magnetosphere, in Physics of the hot plasma in the magnetosphere, Hultquist & Stenflo eds, Plenum Press, New York N Y.

56. Hardy D A et al 1982, DMSP optical and electron measurements in the vicinity of polar cap arcs, J Geophys Res 87, 2413.

57. Heelis R A 1982, The polar ionosphere, Rev Geophys 20, 567.

58. Heelis R A et al 1983, Multistation measurements of high-latitude ionospheric convection, J Geophys Res 88, 10111.

59. Heelis R A & Hanson W B 1980, High-latitude ion convection in the nighttime F region, J Geophys Res 85, 1995.

60. Heelis R A et al 1976, Ion convection velocity reversals in the dayside cleft, J Geophys Res 81.

61. Heelis R A et al 1981, AE-C observations of electric fields around auroral arcs, in Physics of auroral arc formation, 154, Akasofu & Kan eds, AGU, Washington, D C.

62. Heelis R A 1984, The effects of interplanetary magnetic field orientation on dayside high-latitude convection, J Geophys Res 89, 2873.

63. Heikkila W J & Winningham J C 1971, Penetration of magnetosheath plasma to low altitudes through the dayside magnetospheric cusps, J Geophys Res 76, 883.

64. Hill T W & Reiff P H 1977, Evidence of magnetospheric cusp proton acceleration by magnetic merging at the dayside magnetosphere, J Geophys Res 82, 3623.

65. Hirao K 1979, Summary of selected results obtained by the satellite "KYOKKO", in Magnetospheric Study 1979, 11, Japanese IMS Committee, Tokyo.

66. Hoffman R A & Burch J L 1973, Electron precipitation patterns and substorm morphology, J Geophys Res 78, 2867.

67. Hoffman R A & Lin C S 1981, Study of inverted-V auroral precipitation events, in Physics of Auroral Arc Formation, Akasofu & Kan eds, Am Geophysical Union, Washington, D C.

68. Hudson M K et al 1978,, Magnetic field-aligned potential drops due to electrostatic ion cyclotron turbulence, Geophys Res Lett 5, 143.

69. Hudson M K & Mozer F S 1978, Electrostatic shocks, double layers, and anomalous resistivity in the magnetosphere, Geophys Res Lett 5, 131.

70. Hultquist B 1979, The hot ion component of the magnetospheric plasma and some relations to the electron component: Observations and physical implications, Space Sci Rev 23, 581.

71. Hultquist B 1982, Recent progress in the understanding of the ion composition in the magnetosphere and some major question marks, Rev Geophys 20, 589.

72. Ismail S & Meng C -I 1982, A classification of polar cap auroral arcs, Planet Sp Sci 30, 319.

73. Ismail S et al 1977, Characteristics of polar cap sun-aligned arcs, J Geophys Res 82 4741.

74. Johnson R G 1983, The hot ion composition, energy and pitch angle characteristics above the auroral zone ionosphere, in High-latitude space plasma physics, Hultquist & T-Hagfors eds, Plenum Publ.

75. Johnson R G 1979, Energetic ion composition in the earth's magnetosphere, Rev of Geophys Sp Physics 17, 696.

76. Johnson R G et al 1982, Hot plasma composition results from the SCATHA spacecraft, in Energetic Ion Composition in the Earth's Magnetosphere, R G Johnson ed, Terra Sci Publ Co, Tokyo, Japan.

77. Johnstone A D 1978, Pulsating auroras, Nature 274, 119.

78. Kaneda E 1979, Auroral TV observations by KYOKKO, in Magnetospheric Study 1979, 15, Japanese IMS Committee, Tokyo.

79. Kaye S M et al 1981, Observations of transient H^+ and O^+ bursts in the equatorial magnetosphere, J Geophys Res 86, 1335.

80. Kaye S M et al 1981, Ion composition of zipper events, J Geophys Res 86, 3383.

81. Kindel J M and Kennel C F 1971, Topside current instabilities, J Geophys Res 76, 3055.

82. Kintner P M et al 1979, Simultaneous observations of energetic (keV) upstreaming ions and electrostatic hydrogen cyclotron waves, J Geophys Res 84, 7201.

83. Kletzing C et al 1983, Evidence for electrostatic shocks as the source of discrete auroral arcs, J Geophys Res 88, 4105.

84. Klumpar D M 1979, Transversely accelerated ions: an ionospheric source of hot magnetospheric ions, J Geophys Res 84, 4229.

85. Klumpar D M 1980, ISIS observations of auroral particles and large-scale Birkeland currents, in Exploration of the Polar Upper Atmosphere, Deehr & Holtet eds, 329, D Reidel Publ.

86. Klumpar D M 1981, Transversely accelerated ions in auroral arcs, in Physics of Auroral Arc Formation, Akasofu & Kan eds, 22, Am Geophysical Union, Washington, D C.

87. Knight S 1973, Parallel electric fields, Planet Space Sci 21, 741.

88. Knott, K & Battrick B eds 1976, The Scientific Satellite Programme During the International Magnetospheric Study, Proceedings of 10th ESLAB Symposium, Vienna Austria, D. Reidel publ.

89. Lemaire J & Scherer M 1973, Plasma sheet particle precipitation: a kinetic model, Planet Space Sci 21, 281.

90. Lemaire J & Scherer M 1974, Ionosphere-plasma sheet field-aligned currents and parallel electric fields, Planet Space Sci 22, 1485.

91. Lemaire J & Scherer M 1977, Field-aligned distribution of plasma mantle and ionospheric plasma, J Atmos Terr Phys.

92. Lin C S & Hoffman R A 1979, Characteristics of inverted-V events, J Geophys Res 84, 1514.

93. Lin C S & Hoffman R A 1979, Fluctuations of inverted-V electron fluxes, J Geophys Res 84, 6547.

94. Lui A T Y et al 1982, Large amplitude undulation on the equatorial boundary of the diffuse aurora, J Geophys Res 87, 2385.

95. Lundin R et al 1982, Composition of the hot magnetospheric plasma as observed with the Prognoz-7 satellite, preprint, Kirune Geophysical Institute.

96. Lundin et al 1982, Observations of outflowing ion beams on auroral field lines at altitudes of many earth radii, Planet Space Sci 30, 715.

97. Lysak R L & Dum C T 1983, Dynamics of magnetosphere-ionosphere coupling including turbulent transport, J Geophys Res 88, 365.

98. Mauk B H & Meng C I 1983, Dynamical injections as the source of near geostationary quiet time particle spatial boundaries, J Geophys Res 88, 10,011.

99. Mauk B H & Meng C I 1983, Characterization of geostationary particle signatures based on the "injection boundary" model, J Geophys Res 88, 3055.

100. Maynard N C & Johnstone A D 1974, High-latitude dayside electric field and particle measurements, J Geophys Res 79, 3111.

101. McCormac F G & R W Smith 1984, The influence of the interplanetary magnetic field component By on the dayside polar thermospheric flow, in Achievements of the IMS, 25th COSPAR conf.

102. McIlwain C E 1981, Cold plasma boundaries and auroral arcs, in Physics of Auroral Arc Formation, Akasofu & Kan eds, 173, Am Geophysical Union, Washington D C.

103. Meng C -I 1981, Polar cap arcs and the plasma sheet, Geophys Res Lett 8, 273.

104. Meng C -I & Kroehl H W 1977, Intense uniform precipitation of low-energy electrons over the polar cap, J Geophys Res 16, 2305.

105. Meng C -I et al 1979, Electron precipitation of evening diffuse aurora and its conjugate electron fluxes near the magnetospheric equator, J Geophys Res 84, 2545.

106. Meng C -I 1981, Auroral arcs observed by DMSP satellites, in Physics of Auroral Arc Formation, 67 Akasofu & Kan eds, AGU, Washington D C.

107. Mizera P F et al 1975, Electron fluxes and correlations with quiet time auroral arcs, J Geophys Res 80, 2129.

108. Mizera P F et al 1976, Electron pitch-angle distributions in an inverted 'V' structure, Geophys Res Lett 3, 149.

109. Mizera P F & Fennell J F 1978, Satellite Observations of polar magnetotail lobe and interplanetary electrons at low energies, Rev Geophys & Sp Sci 16, 147.

110. Mizera P F et al 1981, The aurora inferred from S3-3 particle and fields, J Geophys Res 86, 2329.

111. Mizera P F et al 1981, Charged particle distributions and electric field measurements from S3-3, J Geophys Res 86, 7566.

112. Mizera P F et al 1982, Experimental verification of an 'S' shaped potential structure, J Geophys Res 87, 1535.

113. Mizera P F et al 1978, Correlated observations of auroral arcs, electrons, and X-rays from a DMSP satellite, J Geophys Res 83, 5573.

114. Moore T E 1984, Superthermal ion signatures of auroral acceleration processes, J Geophys Res, to be published.

115. Mozer F S 1981, IEEE-1 observations of electrostatic shocks on auroral zone field lines between 2.5 and 7 earth radii, Geophys Res Lett 8, 893.

116. Mozer F S et al 1977, Observations of paired electrostatic shocks in the polar magnetosphere, Phys Rev Lett 38, 292.

117. Mozer F S et al 1979, The dc and ac electric field, plasma density, plasma temperature, and field-aligned current experiments on the S3-3 satellite, J Geophys Res 84, 5875.

118. Mozer F S et al 1980, Satellite measurements and theories of low altitude auroral particle acceleration, Space Sci Rev 27, 155.

119. Oguti T 1976, Recurrent auroral patterns, J Geophys Res 81, 1782.

120. Oguti T 1981, Television observations of auroral arcs, in Physics of Auroral Arc Formations, Akasofu & Kan eds, 31, AGU, Washington DC.

121. Oksman J et al 1984, Afternoon radar aurora and polar cap convection pattern, in Achievements of the IMS, 25th COSPAR meeting.

122. Olsen R C 1982, Field-aligned ion streams in the earth's midnight region, J Geophys Res 87, 3481.

123. Papadopoulous K & Coffey T 1974, Nonthermal features of the auroral plasma due to precipitation electrons, J Geophys Res 79, 674.

124. Paschmann G et al 1976, Plasma and magnetic field characteristics of the distant polar cusp near local noon: the entry layer, J Geophys Res 81, 2883.

125. Paschmann G et al 1972, Angular distributions of auroral electrons in the energy range 0.8-16 keV, J Geophys Res 77, 6111.

126. Perkins F W 1968, Plasma-wave instabilities in the ionosphere over the aurora, J Geophys Res 73, 6631.

127. Peterson W K et al 1982, Energetic ion composition in the subsolar magnetopause and boundary layer, J Geophys Res 87, 2139.

129. Reiff P H 1982, Sunward convection in both polar caps, J Geophys Res 87, 5976.

130. Reiff P H 1983, Polar and auroral phenomena: a review of U.S. progress during 1979-1982, Rev Geophys Space Phys 21, 418.

131. Reiff P H et al 1978, Dayside auroral arcs and convection, Geophys Res Lett 5, 391.

132. Reiff P H et al 1977, Solar wind plasma injection at the dayside magnetospheric cusp, J Geophys Res 82, 479.

133. Reasoner D L & Chappell C R 1973, Twin payload observations of incident and backscattered auroral electrons, J Geophys Res 78, 2176.

135. Rosenbauer H et al 1975, HEOS 2 plasma observations in the distant polar magnetosphere: the plasma mantle, J Geophys Res, 2723.

136. Roywick O & Davis T N 1977, Pulsating aurora: local and global morphology, J Geophys Res 82, 4720.

137. Russell C T & Southwood D J eds 1982, The IMS Source Book, Am Geophysical Union, Washington D C.

139. Sharp R D et al 1977, Observation of an ionospheric acceleration mechanism producing energetic (keV) ions primarily normal to the geomagnetic field direction, J Geophys Res 82, 3324.

140. Sharp R D et al 1983, Hot plasma composition results from S3-3 spacecraft, in Energetic ion composition in the earth's magnetosphere, R G Johnson ed, 167, Terra Sci Publ Co, Tokyo.

141. Sharp R D et al 1983, Hot plasma composition results from the ISEE-1 spacecraft, in Energetic Ion Composition in the Earth's Magnetosphere, R G Johnson ed, 231, Terra Sci Publ Co, Tokyo.

142. Sharp R D et al 1979, Energetic particle measurements from within ionospheric structures responsible for auroral acceleration processes, J Geophys Res 84, 480.

143. Sharp R D et al 1982, The origins of the plasma in the distant plasma sheet, J Geophys Res 87, 10420.

144. Shawhan S D et al 1978, On the nature of large auroral zone electric fields at 1-R_e altitude, J Geophys Res 83, 1049.

145. Shelley E G 1979, Ion composition in the dayside cusp; injection of magnetospheric ions into the high latitude boundary layer, in Proceedings of Magnetospheric Boundary Layers Conference, Alpbach ESA SP-148.

146. Shelley E G et al 1972, Satellite observations of energetic heavy ions during a geomagnetic storm, J Geophys Res 77, 6104.

147. Shelley E G et al 1982, The polar ionosphere as a source of energetic magnetospheric plasma, Geophys Res Lett 9, 841.

148. Shelley E G et al 1976, Satellite observations of an ionospheric acceleration mechanism, Geophys Res Lett 3, 654.

149. Shelley E G et al 1976, He^{++} and H^{+} flux measurements in the dayside cusp: estimates of convection electric field, J Geophys Res 81, 2363.

150. Singh N et al 1981, Energization of ionospheric ions by electrostatic hydrogen cyclotron waves, Geophys Res Lett 8, 1249.

152. Swift E W 1970, Particle acceleration by electrostatic waves, J Geophys Res 75, 6324.

153. Swift D W 1975, On the formation of auroral arcs and acceleration of auroral electrons, J Geophys Res 80, 2096.

154. Swift D W 1977, Turbulent generation of electrostatic fields in the magnetosphere, J Geophys Res 82, 5143.

155. Temerin M et al 1981, Paired electrostatic shocks, Geophys Res Letters 8, 799.

156. Temerin M et al 1981, The small-scale structure of electostatic shocks, J Geophys Res 86.

157. Torbert R B & Carlson C W 1976, Impulsive ion injections into the polar cusp, in Magnetospheric Particles and Fields, B M McCormac ed, 47, D Reidel, Dordrecht, Netherlands.

158. Torbert R B & Carlson C W 1980, Evidence for parallel electric field particle acceleration in the dayside auroral oval, J Geophys Res 85, 2909.

159. Torbert R B & Mozer F S 1978, Electrostatic shocks as a source of discrete auroral arcs, Geophys Res Lett 5, 125.

160. Vampola A L 1971, Access of solar electrons to closed field lines, J. Geophys Res 76, 36.

161. Wahlen B A & McDiarmid I B 1972, Observations of magnetic-field-aligned auroral-electron precipitation, J Geophys Res 77, 191.

162. Wahlen B A et al 1978, Low altitude acceleration of ionospheric ions, Geophys Res Lett 5, 55.

163. Winningham J D 1972, Characteristics of magnetosheath plasma observed at low altitude in the dayside magnetospheric cusps, in Earth's Magnetospheric Processes, B M McCormac ed, 68, D Reidel, Dordrecht, Netherlands.

164. Winningham J D et al 1975, The latitudinal morphology of 16-eV to 10-keV electron fluxes during magnetically quiet and disturbed times in the 2100-0300 MLT sector, J Geophys Res 80.

165. Winningham J D et al 1984, Bands of ions and angular V's: a conjugate manifestation of ionospheric ion acceleration, J Geophys Res 89, 1749.

166. Yeager D M & Frank L A 1976, Low-energy electron intensities at large distances over the earth's polar caps, J Geophys Res 81, 3966.

167. Yau A W et al 1984, Distribution of upflowing ionospheric ions in the high-altitude polar cap and auroral ionosphere, J Geophys Res to be published.

168. Young D T 1979, Ion composition measurements in magnetospheric modeling, in Quantitative Modeling of Magnetospheric Processes, W P Olson ed 340, Am Geophysical Union, Washington D C.

169. Young D T 1983, Near-equatorial magnetospheric particles from ~1 eV to ~1 MeV, Rev Geophys Space Phys 21, 402.

170. Young D T et al 1981, Observed increase in the abundance of kilovolt O^+ in the magnetosphere due to solar cycle effects, Adv Space Res 1, 309.

171. Young D T et al 1977, Discovery of He^{2+} and O^{2+} ions of terrestrial origin in the outer magnetosphere, Geophys Res Lett 4, 551.

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, environmental hazards, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiation transport in rocket plumes, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Electronics Research Laboratory: Microelectronics, GaAs low noise and power devices, semiconductor lasers, electromagnetic and optical propagation phenomena, quantum electronics, laser communications, lidar, and electro-optics; communication sciences, applied electronics, semiconductor crystal and device physics, radiometric imaging; millimeter wave, microwave technology, and RF systems research.

Information Sciences Research Office: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence and microelectronics applications.

Materials Sciences Laboratory: Development of new materials: metal matrix composites, polymers, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.